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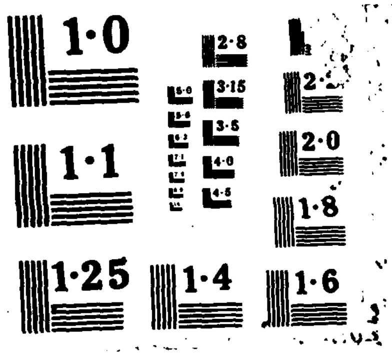
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LOCH LINNHE EXPERIMENT DATA SUMMARY

23 November 1987

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1. Introduction

During the Loch Linnhe Experiment, TRW deployed a ground truth package of instrumentation on board the Loch Nevis. The package consists of the following 4 main instruments:

(i) Scanning laser slope gauge

(ii) X-and Ka-band radars

(iii) Wave height probe

(iv) A photographic system for detecting and measuring specular joints

The following auxiliary instruments are also deployed in a supporting role:

(i) An inclinometer to measure the pitch and roll of the slope gauge due to ship motion

(ii) A salinity gauge (on loan to us from Anton Edwards of SMBA) for detecting the presence or arrival of an internal wave

(iii) A video camera for recording general conditions of the sea surface around the slope gauge.

A brief description of the main instruments can be found in the following sections. The last section is a data log summary showing the data taken as well as its assessed quality.

2. Scanning Laser Slope Gauge

Description

The major components of the scanning laser slope gauge are shown in Figure 1. The beam from the argon laser is directed down through a nitrogen filled tube to the x-y scanner below the water surface. The scanner then redirects it upward toward the surface where it scans a raster pattern with the nominal characteristics listed in Table 1. Angle transducers within the x-y scanner indicate the direction of the beam as it exists the scanner. Knowledge of this as well as water surface height and the position where the beam hits the detector provides the information necessary to calculate the slope of the water surface at the point of incidence. The 2 axis inclinometer allows corrections to be made for platform pitch and roll.

However, these corrections are small and very slowly varying compared to scanned slope of 3 cm waves.

TABLE 1. Slope Gauge Characteristics

Scan Geometry	5 lines, 50 cm long, spaced 9.5 cm apart
Scan Rate	150 lines per second
Spot Size	0.4 mm diameter
Sun Discrimination	Modulated laser and phase sensitive detection frequency response 36 kHz
Support Instruments	Wave height gauge 2 axis inclinometer

Near the scanner is a lens which focuses the beam of the water surface. The calculated diffraction limited spot diameter at the mean water height is 0.4 mm. The 3.3 m rad. divergence of the beam results in the spot size increasing to approximately 1.0 mm diameter with water height changes of $\pm$ 300 mm from the mean level.

Loch Linnhe water optical effects. It has been suggested by others that particulates in the water might scatter the light to the extent that the laser beam would spread to a diameter too large to resolve centimeter water waves. To investigate this photographs were taken of the laser spot in calm water when the Loch Nevis was tied to the pier. These showed that the spot size varied rapidly with time between 0.4 mm and 1.0 mm. Inhomogeneities in the index of refraction of the water having a characteristic scale the order of 10 mm were visually observed in the column of water through which the laser beam passes. These inhomogeneities, probably due to mixing of the fresh and salt water in the shallow region near the pier, probably cause this slight focus degradation which should have negligible effect on our instruments.

While there was no evidence of significant beam spread due to scattering, there was considerable transmission loss through the water. In order to get a rough idea what the loss was, water samples were taken periodically at the test site. The

transmission of these samples was measured at the argon laser wavelength, 514 nm, and found to be characterized by an absorption coefficient ranging from 0.83 m^{-1} to 1.05 m^{-1} resulting in transmittance through the 1.462 m underwater path ranging from 0.30 to 0.22. Laser output power was increased to compensate for some of this loss. Data reduction techniques provide normalization to compensate for laser power variations.

Data quality. The slope gauge operated for the duration of the tests with the exception of the last run on the last day; Run 4 on 21 September 1987. The laser failed to start for this run. Operator problems resulted in low signal level for Runs 1 and 2 on 3 September 1987 which will result in degraded slope resolution. Disconnected leads resulted in loss of signal in 5 of the detector channels on Run 3 on 5 September 1987 which may not be reducible with software developed for an 8 detector sensor. Two changes were made in the raster scan early in the program. The scan lines were changed from a sawtooth pattern in which the scan lines were at an angle of 11 degrees to the Loch Nevis heading to a scan parallel to her heading. This change was effective starting 5 September 1987. Starting 10 September 1987 the scan rate was changed from 150 lines per second to 156.25 lines per second to facilitate more efficient data processing. Because of this, software developed to process the bulk of the data obtained starting 10 September 1987 will require modification to process data taken on 3 and 5 September 1987.

3. X- and Ka-Band Radars

Description

Both X-and Ka-band radars have the following characteristics:

(i) CW fixed frequency superhet system

(ii) Coherent — both amplitude and phase measured

(iii) Dual polarized in vv and hh

(iv) Focused at 1 meter

Their differences are summarized in the following table:

	X-Band	Ka-Band
Frequency	9.23 GHz	38.0 GHz
Power	1 watt	250 mW
3 dB spot size at 1 m	18 cm	13 cm

The X-band system uses 2 klystrons as local oscillators and transmitters whereas the Ka-band system uses 2 Varactor-tuned Gunn diodes. Since both systems are phase-locked using frequency stabilizers and synchronizers, they behave the same operationally. Both systems mix the local oscillator signal with the reflected signal to produce a 30 mHz IF. The IF is first downconverted to 20 kHz by vector voltmeters (which also act as tuning indicators) and then downconverted a second time using frequency synthesizers and low frequency mixers to about 400 Hz. This signal, which contains both the amplitude and phase information, is being recorded onto digital tape.

The 2 radar antennas are mounted side by side close to the edge of the slope gauge detector box (see Figure 1). Incidence angle for both horn antennas is fixed at 40° and distance to water surface is 1 m. The X-band radar footprint on the water surface is traversed symmetrically by 3 laser scan lines whereas the Ka-band radar footprint is cut through by 1 scan line. This will make possible the comparison between laser slope data and radar data when detailed analysis is performed.

Radar calibration was performed by swining a 5/8" stainless steel sphere through the antenna patterns and measuring the Doppler spectrum. This was performed once for each test period.

Data Quality

The X-band radar performed almost flawlessly throughout the experiment. The radar was phase-locked so well that hardly any adjustment need be made in the course of an afternoon. Consequently, tuning of the X-band radar to minimize stray

reflections and drifting was quite easy. While the data was being recorded, its Doppler spectrum was observed simultaneously on a real-time spectrum analyzer. Judging from the spectrum analyzer display, the data should be excellent.

Ka-band radar was harder to work with than X-band. Phase-locking was harder in the first place, probably because of weaker signal and because of the higher frequency. It was not uncommon to lose lock several times during a run, although there were several good runs during which phase locking was perfect. The vv channel was drifting very rapidly for some unknown reason for most of the runs. Typically, this behavior is the result of some loose waveguide joints. During the week of September 6-12, all waveguide joints were checked and tightened. Flexible waveguides on the vv channel were replaced or shortened where possible. The interior of the waveguide was also flushed with dry nitrogen. All these measures were of no avail as the drifting problem continued. Consequently, practically no useful data was obtained in Ka-band vv. Ka-band hh channel, however, behaved quite nicely and judging from the spectrum analyzer display, the quality of the data should be quite good. A summary of data quality can be found in the data log summary.

4. Wave Height Probe

The wave height probe used in this experiment was an instrument built to the specifications of the wave wire system developed by Blyth Hughes of DREP. It uses a passivated tantalum wire driven by a low frequency AC signal. Changes in wave height, or depth of immersion, vary the capacitance of the wire which in turn changes the current through the wire. This AC current change is converted into an AC voltage which can be rectified to a DC voltage. The DC voltage is linearly proportional to the wire capacitance which is equivalent to the immersion length of the wire.

In order to make the tantalum wire a capacitor, it has to be passivated. This is accomplished by passing a low level current (5 ma) at a high DC voltage (100 v) through the wire. This procedure results in a very thin, but tough, oxide being

built up on the wire surface. By keeping the high voltage on during operation of the gauge, added to the AC signal, any breaks in the insulation are very quickly repaired. Damage can occur to the wire when solid material, such as sea weed, hits the wire.

During operation of the wire probe it is important to keep the tantalum wire from contacting any ground plane metal since the thin oxide layer can be damaged by shorting the DC voltage to ground. With this problem in mind the three wave height gauges used in the experiment were attached to the laser slope gauge by means of nonconductive blocks, and fastened to the blocks by friction clamps. During the first set of experimental trials, September 2, 3 and 5, it was found that the friction clamps were insufficient to keep the wires from slipping out of the clamps when objects such as sea weed flowed past the wires.

Although final reduction of the wave height data has not been performed, initial assessment of the data shows it to be very good. Both linearity and calibration of each of the wires are very constant and should provide an excellent record of wave height conditions encountered during the trials.

5. Specular Point Measurement System

To detect and measure the radii of curvature of specular points, a 35 mm Nikon camera system was deployed as a "poor man's" 35 mm movie system. The camera has a 250 frame back so that at 5 frames/second, 50 seconds of data can be taken at a time. It has a 90 mm lens as well as 2 rapid firing flashes which can fire as fast as 5 times/second. The flashes are covered by red and yellow filters respectively so that their images in the specular points will be bright red-yellow point pairs. Laboratory testing of this arrangement has shown that radii of curvature of specular points can be obtained by measuring the separation between the red and yellow points. The camera and flash lamp mounting geometry is shown in Figure 1. Loch Linnhe was meant to be a testing and development stage for the system. Data will be carefully analyzed to facilitate future full scale deployment.

6. <u>Data Log Summary</u>

EXPLANATION OF ABBREVIATIONS

TYPE	ENV	BRIGHT NARROW V-WAKE
	WW	Wind wave run made by Loch Nevis after completion of daily program
	IW	Internal wave run
	AB BA CD EF	Start and end points of Roysterer runs, as indicated on maps of Loch Linnhe Test Plans
	KNT	Ship or wind speed in knots
	MPS	Ship or wind speed in meter per second
Microwave Tuning	X	X-band microwave instrument
	Ka	Ka-band microwave instrument
	VV	VV polarization
	HH	HH polarization
	INTERM	Intermittent operation due to locking or tuning problems
Comments	WH	Wave height gauge

DATE	RUN NO	TYPE	SLOPE TIME	μ-WAVE TIME	WAVE-HEIGHT TIME	HONEYWELL TAPE NO	PHOENIX		PC DISK NAME FILE NAME	VIDEO TAPE NO	SLOPE QUALITY	μ-WAVE TUNING				CONDUCTIVITY PROBE INTERNAL WAVE SIGNAL	LOCH NEVIS		WIND		SEA STATE	COMMENTS
							TAPE NO	FILE NO				X VV	X HH	Ka VV	Ka HH		HEAD	SPEED	DIRECTION	SPEED		
9 2	1		16 41 16 54	16 41 16 56 30		1	1	1		1												CHECKOUT. NO WAVE HEIGHT DATA
9 3	1		16 31 30 16 41 30	16 34 30 16 41 30		2	1	2		1	LOW SIGNAL											INTERMITTENT WAVE HEIGHT
	2		17 48 17 58	17 48 17 58	17 48 17 58	3	1	3	93 2	1	LOW SIGNAL	√	√	INTERM			202					ONLY 1 WAVE HEIGHT
	3		19 14 19 16 30	19 14 19 17 30	19 14 19 17 30	3	1	4	93 3	1		√	√	INTERM			234					
9 5	1	BNV AB 12 KNT	14 54 30 15 03	14 54 30 15 03	14 54 30	4	2	1	SEPT 5A SEPT 5 1	2	GOOD	√	√	NO			166		200	10 KNT	1' MAX GOING FLAT	NO COND OUTPUT 2 WAVE GAGES — NO 3 BAD SMALL KELVIN WAKE
	2	BNV BA 12 KNT	15 44 45 15 54	15 44 45 15 54	15 44 45 15 54	5	2	2	SEPT 5A SEPT 5 2	2	GOOD	√	√	NO			163				FLAT	POSSIBLE GOOD RUN
	3	BNV AB 12 KNT	17 04 17 13 30	17 04 17 13 30	17 04 17 13 30	6	2	3	SEPT 5B SEPT 5 3	2	INTERM	√	√	NO			134				FLAT	POSSIBLE GOOD RUN
	4	BNV BA	17 58 10 18 06	17 56 18 06	17 56 18 06	7	2	4	SEPT 5B SEPT 5 4	2	GOOD	√	√	NO			132				SMALL WAVES	WH #3 SEAWEED POSSIBLE GOOD RUN
	5	WW	18 35 18 42 20	18 35 18 44 25	18 35 18 44 25	7	2	5	SEPT 5C SEPT 5 5	2	GOOD	√	√	LOW SIGNAL			200	1 5 KNT			6" 1'	WH #2 GONE STILL NO COND WAVES TO BLACK MARK POSSIBLE GOOD LIGHT WIND RUN

DATE	RUN NO	TYPE	SLOPE TIME	μ-WAVE TIME	WAVE-HEIGHT TIME	HONEYWELL TAPE NO	PHOENIX		PC	VIDEO TAPE NO	SLOPE QUALITY	μ-WAVE TUNING				CONDUCTIVITY PROBE INTERNAL WAVE SIGNAL	LOCH NEVIS		WIND		SEA STATE	COMMENTS
												X		Ka								
							TAPE NO	FILE NO	DISK NAME FILE NAME			VV	HH	VV	HH		HEAD	SPEED	DIRECTION	SPEED		
9 14	2	BNV B A 6 MPS	14 30 30 14 43 15	14 30 30 14 43.15	14 30 30 14 43 15	10	3	1	SEPT 14A SEPT 14 1	3	GOOD	√	√	LOCKED		NO	125					POSSIBLE GOOD RUN, HIGH SEA COND PROBE OPERATING SPECULAR REFL. DATA
	3	BNV A B 6 MPS	15 49 16 01	15 49 16 01	15 49 16 01	11	3	2	SEPT 14B SEPT 14 2	3	GOOD	√	√	LOCKED NO VV		NO	139					SPECULAR REFL DATA GOOD RUN, HIGH SEA
	4	BNV B A 6 MPS	16 40 16 52	16 40 16 52	16 40 16 52	12	3	3	SEPT 14C SEPT 14 3	3	GOOD	√	√	BAD TUNING		NO	105					GOOD RUN
	5	WW	17 27 17 32	17 27 17 32	17 27 17 32	13	3	4	SEPT 14C SEPT 14 4	3	GOOD	√	√	INTERM NO VV		NO	214	1 KNT				RAIN IN PART OF DATA MODERATE WW RUN GOOD
9 15	1	IW CD	12 26 12 37 40	12 26 12 38 30	12 26 12 38 30	14	4	1	SEPT 15A SEPT 15.1	4	GOOD	√	√	INTERM NO VV		YES	220		203 5	10 KNT	1'	VARIABLE RAIN STRONG SLOPE INFLUENCE, POSSIBLY GOOD RUN
	2	IW CD	13 53 45 14 05	13 53 45 14 06	13 53 45 14 06	15	4	2	SEPT 15B SEPT 15 2	4	GOOD	√	√	INTERM NO VV		YES	210					VARIABLE RAIN GOOD RUN
	3	IW EF	15 27 15 39 20	15 27 15 39 20	15 27 15 39 20	16	4	3	SEPT 15C SEPT 15 3	4	GOOD	√	√	INTERM NO VV		POSSIBLE	225				FLAT	GOOD RUN
	4	WW	16 41 16 46	16 41 16 46	16 41 16 46	17	4	4	SEPT 15C SEPT 15 4	4	GOOD	√	√	HH TUNED NO VV		NO	195	2 KNT			FLAT	GOOD LIGHT WW RUN
9 16	1	BNV A B 6 MPS	12 34 45 12 48	12 34 45 12 50	12 37 45 12 50	18	5	1	SEPT 16A SEPT 16 1	5	GOOD	√	√	HH INTERM NO VV		NO	155					NO WH DURING KW
	2	BNV B A 6 MPS	13 30 15 13 45	13 29 45 13 48	13 29 45 13 48	19	5	2	SEPT 16B SEPT 16 2	5	GOOD	√	√	HH INTERM NO VV		NO	156					GOOD RUN
	3	BNV AB 6 MPS	14 47 45 15 02 20	14 47 30 15 05 40	14 47 30 15 05 40	20	5	3	SEPT 16C SEPT 16 3	5	GOOD	√	√	HH INTERM NO VV		NO	155					GOOD RUN

DATE	RUN NO	TYPE	SLOPE TIME	μ-WAVE TIME	WAVE-HEIGHT TIME	HONEYWELL TAPE NO	PHOENIX TAPE NO	PHOENIX FILE NO	PC DISK NAME FILE NAME	VIDEO TAPE NO	SLOPE QUALITY	μ-WAVE TUNING X VV	μ-WAVE TUNING X HH	μ-WAVE TUNING Ka VV	μ-WAVE TUNING Ka HH	CONDUCTIVITY PROBE INTERNAL WAVE SIGNAL	LOCH NEVIS HEAD	LOCH NEVIS SPEED	WIND DIRECTION	WIND SPEED	SEA STATE	COMMENTS
9 16	4	RNV RA 6 MPS	15 39 15 53 30	15 38 30 15 56 45	15 38 30 15 56 45	21	6	1	SEPT 16D SEPT 16 4	6	GOOD	√	√	NO	√	YES	155					GOOD RUN
	5	WW	16 23 16 28	16 23 16 28	16 23 16 28	22	6	2	SEPT 16E SEPT 16 5	6	GOOD	√	√	INTERM NO VV		NO	215	2 KNT				GOOD MODERATE WW RUN
9 17	1	IW CD	14 30 14 51 30	14 30 14 48	14 30 14 48	23	7	1	SEPT 17A SEPT 17 1	6	GOOD	√	√	INTERM NO VV		YES	214					GOOD RUN STRONG IW VARIABLE WIND
	2	IW CD	16 02 30 16 14	15 56 16 14	15 56 16 14	24	7	2	SEPT 17B SEPT 17 2	6	GOOD	√	√	INTERM NO VV		YES	213					BAD RUN, MISSED STRONG IW WITH SLOPE GAGE
	3	IW EF	17 30 30 17 45	17 30 30 17 48 40	17 30 30 17 48 40	25	7	3	SEPT 17C SEPT 17 3	7	GOOD	√	√	NO	√	YES	208					GOOD RUN
	4	WW	18 25 18 31	18 25 18 30	18 25 18 30	26	8	1	SEPT 16E SEPT 17 4	7	GOOD	√	√	NO	√	NO	216	1 KNT		LIGHT	SLIGHT	WH DATA SUSPECT
9 18	1	IW CD	14 29 15 14 50	14 29 15 14 47 20	14 29 15 14 47 20	27	9	1	SEPT 18A SEPT 18 1	7	GOOD	√	√	INTERM NO VV		YES	233		250	20 30 KNT	2'	BIG INTERNAL WAVES GOOD RUN
	2	IW CD	15 57 30 16 09 50	15 56 45 16 15	15 56 45 16 15	28	9	2	SEPT 18B SEPT 18 2	7	GOOD	√	√	INTERM NO VV		YES	236					GOOD RUN
	3	IW EF	17 29 17 43	17 28 30 17 46 30	17 28 30 17 46 30	29	9	3	SEPT 18C SEPT 18 3	8	GOOD	√	√	NO	√	YES			030	>15 KNT	SLIGHT	GOOD RUN
9 20	1	IW CD CROSSING	14 25 20 14 43 45	14 25 20 14 43 45	14 25 20 14 43 45	30	10	1	SEPT 20A SEPT 20 1	8	GOOD	√	√	NO	√	YES		1 5 MPS	150	15 20 KNT	2 3'	SPECULAR PICTURES, GOOD RUN 2 WAKE CROSSINGS
	2	IW CD CROSSING	15 51 16 05 30	15 51 16 05 30	15 51 16 05 30	31	10	2	SEPT 20B SEPT 20 1	8	GOOD	√	√	NO	√	YES		1 5 MPS				GOOD RUN, WIND DYING 2 WAKE CROSSINGS SPECULAR PICTURES

DATE	RUN NO	TYPE	SLOPE TIME	μ-WAVE TIME	WAVE-HEIGHT TIME	HONEYWELL TAPE NO	PHOENIX TAPE NO	PHOENIX FILE NO	PC DISK NAME FILE NAME	VIDEO TAPE NO	SLOPE QUALITY	μ-WAVE TUNING X VV	μ-WAVE TUNING X HH	μ-WAVE TUNING Ka VV	μ-WAVE TUNING Ka HH	CONDUCTIVITY PROBE INTERNAL WAVE SIGNAL	LOCH NEVIS HEAD	LOCH NEVIS SPEED	WIND DIRECTION	WIND SPEED	SEA STATE	COMMENTS
9 20	3	IW EF CROSSING	17 31 17 53 30	17 31 17 53 30	17 31 17 45 17 45 15 17 53 30	32	10	3	SEPT 20C SEPT 20 3 SEPT 20D SEPT 20 4	9	GOOD	√	√	NO	√	YES		1 5 MPS			SLIGHT	GOOD RUN, VERY QUIET SURFACE, 2+ CROSSINGS
9 21	1	BNV AB	14 35 14 55	14 35 14 53	14 35 14 53	33	11	1	SEPT 21A SEPT 21 1	9	GOOD	√	√	NO	√	YES	146 5		240	6 KNTS	LIGHT	GOOD RUN, LIGHT RAIN SEVERAL IW
	2	BNV BA	15 29 30 15 47 30	15 29 30 15 47 30	15 29 30 15 47 30	35	11	2	SEPT 21B SEPT 21 2	9	GOOD	√	√	NO	√	YES	143					GOOD RUN, SPECULAR PICTURES, WIND PICKING UP
	3	BNV AB	16 49 30 17 07 40	16 49 30 17 07 40	16 49 30 17 07 40	36	11	3	SEPT 21C SEPT 21 3	10	GOOD	√	√	INTERM NO VV		YES					FLAT	GOOD RUN, RAINING
	4	BNV BA CROSSING		17 37 30 17 53 30	17 37 30 17 53 30	34	12	1	SEPT 21D SEPT 21 4	10	NONE	√	√	NO	√	YES					FLAT	NO SLOPE DATA, RAINING 2 CROSSINGS

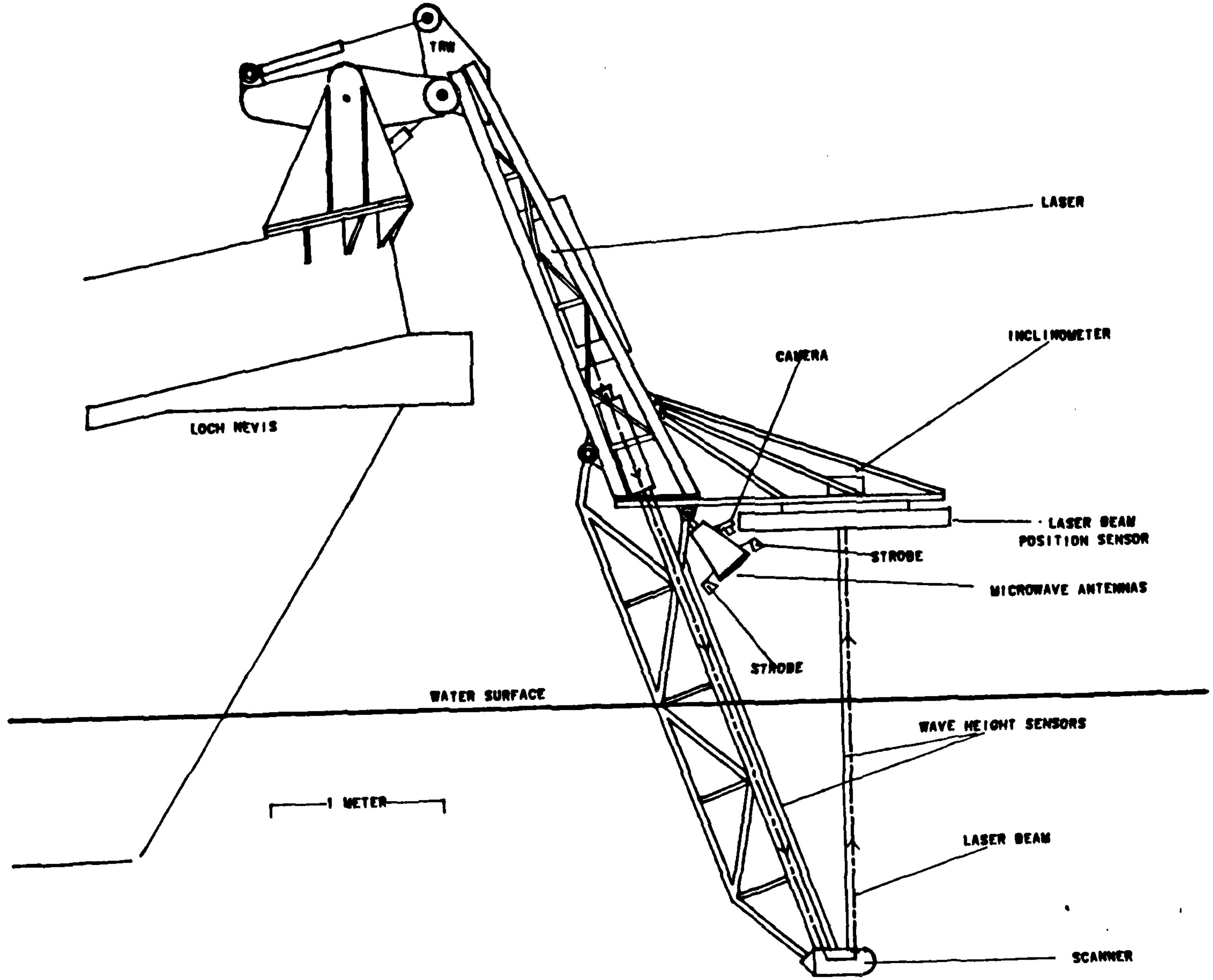

Figure 1. Instrument Suite

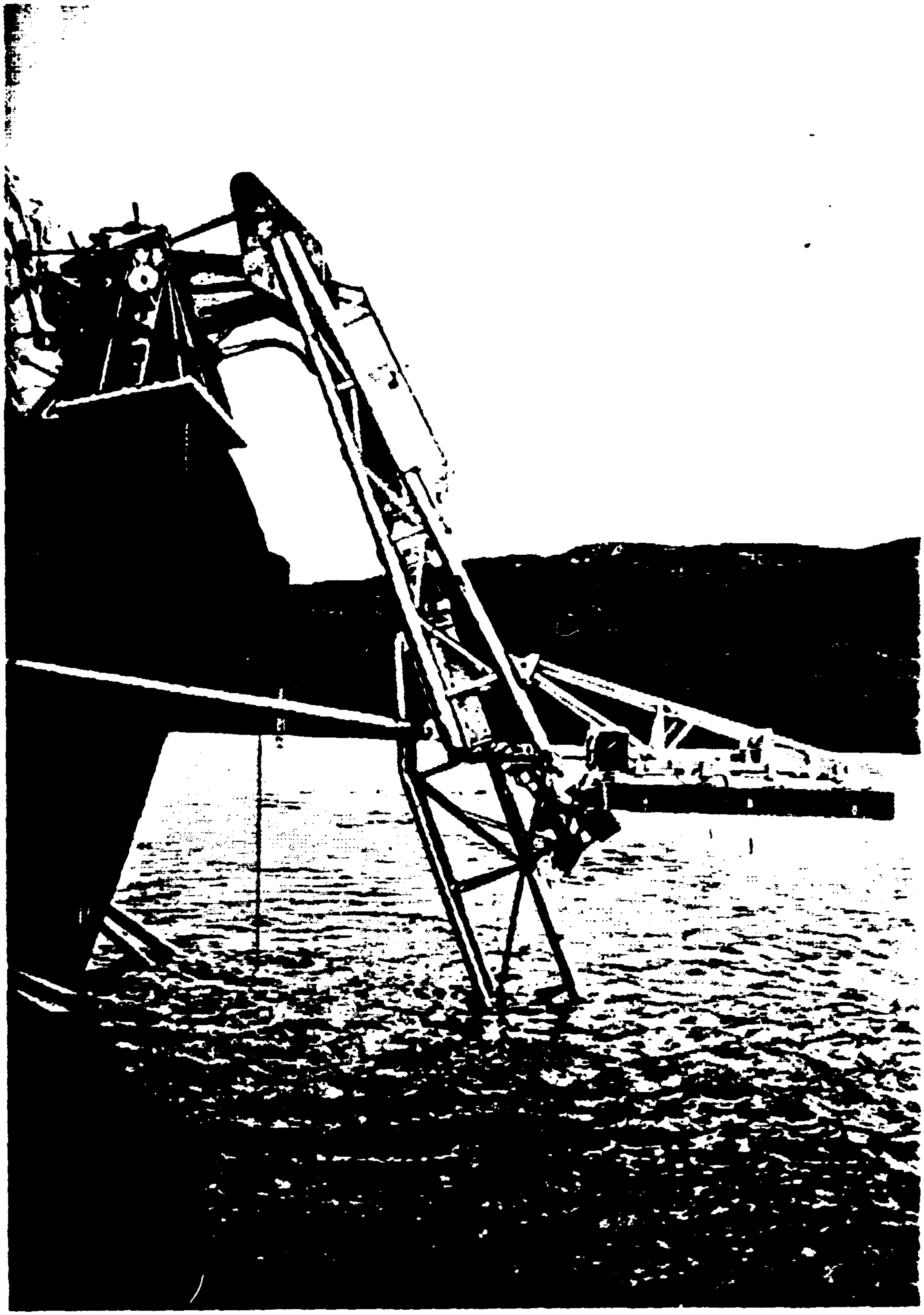

Figure 2. Side view of TRW ground truth instrumentation mounted on Loch Nevis.

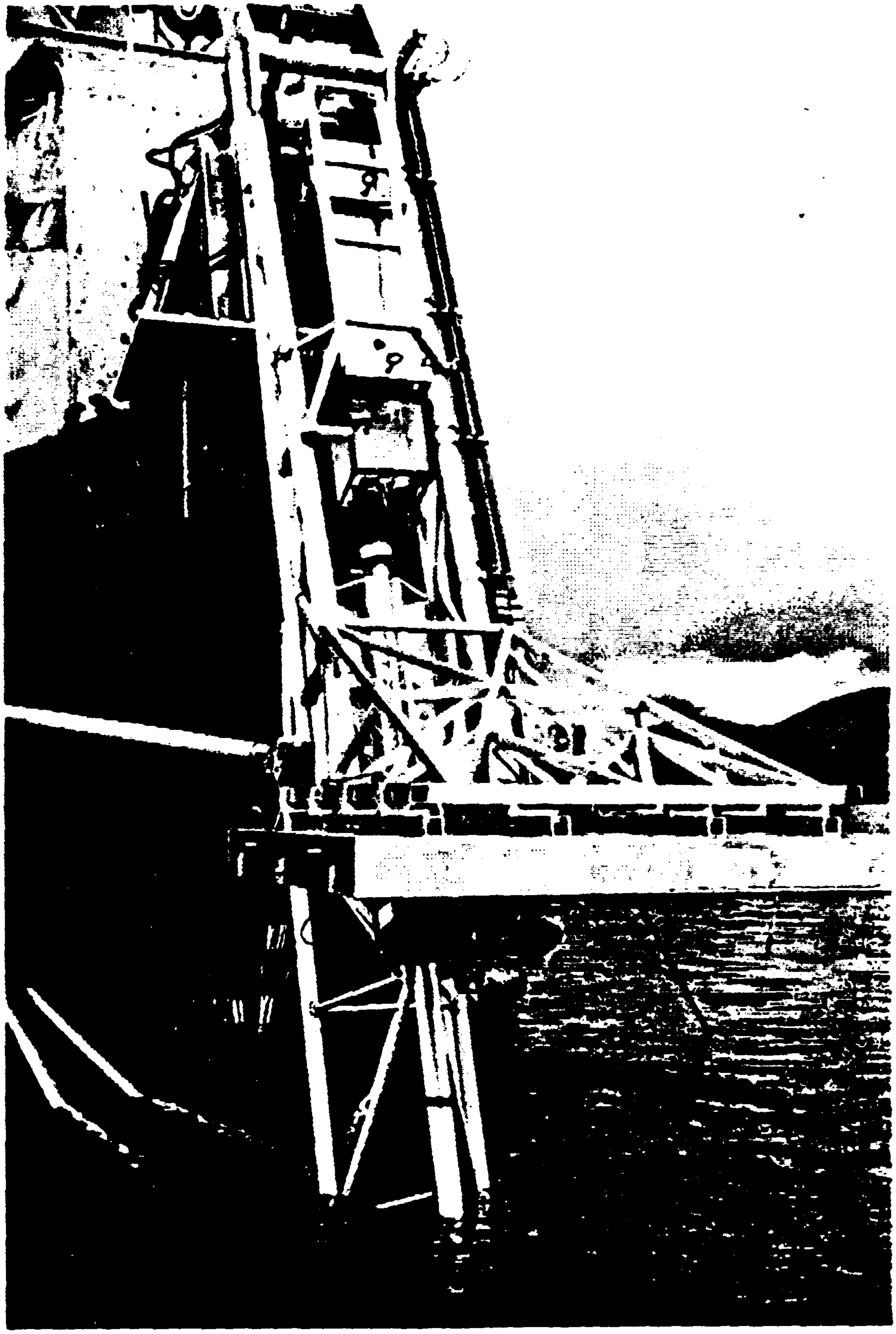

Figure 3. Front view of TRW ground truth instrumentation

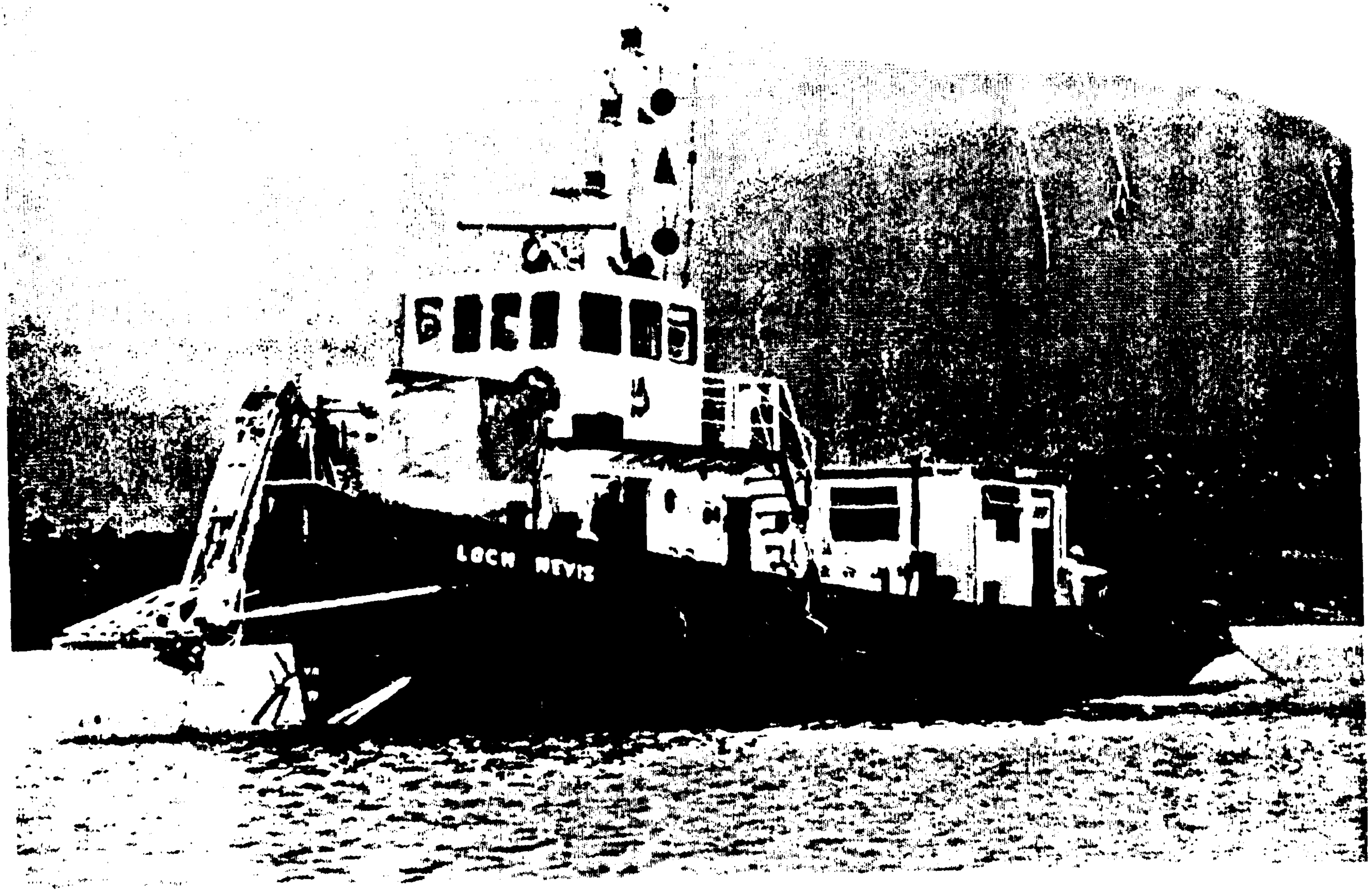

Figure 4. Loch Nevis with TRW instrument in front of bow shack in the bow area contains the 2 radar units. Shack in the back contains rest of instrumentation.

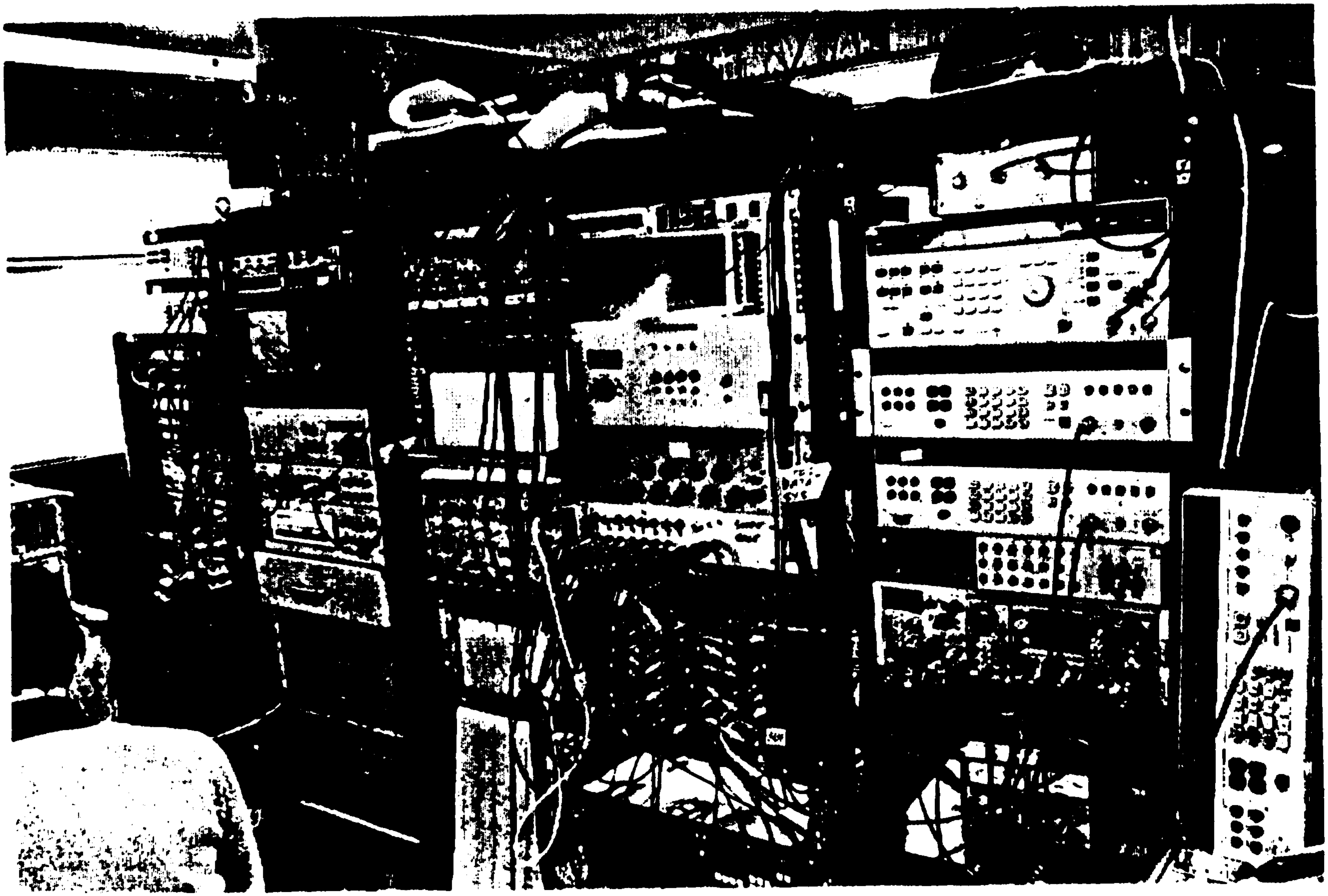

Figure 5. Interior view of rear instrumentation shack

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